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**The Effects of Acute Cold Exposure  
on Exercise Performance**

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## Introduction

In an overall survey of the animal kingdom, humans may be described as warm-weather, sweaty, tropical animals who neither tolerate nor adapt well to the cold. As we know, however, humans have explored the coldest regions of the earth and live in arctic and subarctic environments. Such habitation was made possible through the development of a microclimate of clothing, shelter and fire in order to keep skin temperature close to  $32^{\circ}\text{C}$  ( $89.6^{\circ}\text{F}$ ). Without such a microclimate, humans could not survive at temperatures much below  $20^{\circ}\text{C}$  ( $68^{\circ}\text{F}$ ). Anecdotal evidence suggests that long-term exposure to cold reduces the discomfort of the cold, but there is little evidence that humans have any significant physiologic adaptation to cold with respect to survival.

Because of the microclimate, particularly in the technology of clothing and equipment, more and more individuals are participating in various cold-weather activities. This brief review will examine, therefore, human physiological responses at rest and at exercise during acute cold air exposure and the principle medical problems which can arise from exercise in such an environment.

## Physiological Principles

### THERMOREGULATION.

The homeothermic animal exposed to cold is faced with the problem of a rapid loss of heat and a consequent lowering of body temperature. However, such exposure brings into play a variety of regulatory mechanisms which contribute to the maintenance of a normal body temperature. The human's first response is to decrease heat loss by peripheral vasoconstriction. This is under the influence of the sympathetic nervous system through stimulation of peripheral thermoreceptors. Peripheral vasoconstriction occurs in most

areas of the body with the exception of the head where up to 25% of the total heat loss can take place. At the same time, the splanchnic vessels vasodilate to allow the shunting of blood to the core thereby increasing tissue insulation.

If the environmental temperature continues to decline, heat production mechanisms are initiated. Shivering begins from stimulation of peripheral, as well as, central thermoreceptors and is under control of the central nervous system(CNS). This process involves the normal mechanisms of muscular contraction and the effect of raising heat production is much like that of light exercise. Shivering is an active process and may be considered an exercise response without definite work output. Heat production can be increased 3 to 4 times above resting in the temperature range 0-10°C(32-50°F).

#### CIRCULATORY ADJUSTMENTS

The increased heat production and oxygen uptake due to shivering would appear to be the result of an increased heart rate and cardiac output as occur during mild exercise. However, Raven, et. al.(18) showed (in man at rest exposed to 5°C(41°F) for 2 hours) that an increased cardiac output (heart rate x stroke volume) was primarily due to an increased stroke volume while heart rate remained constant and low. The heart rate response to shivering, therefore, is in striking contrast to the mechanism by which the heart responds to exercise where an increased cardiac output up to an oxygen uptake of 1-2 L/min is primarily due to an increased heart rate.

Higher circulating catecholamine levels may be partly responsible for the increased stroke volume. In addition, peripheral vasoconstriction (powerful enough to cause a shift of blood into the central circulation and increase /



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the mean blood pressure) may also be a key factor. Thus, pressure mechanisms working through the baroreceptors to reflexly depress heart rate may explain why heart rate fails to respond to the increased circulatory demands of cold-exposure.

### The Effect of Cold on Human Performance

#### SUBMAXIMAL EXERCISE RESPONSES

The stimuli of cold and exercise result in opposite, conflicting physiological responses (unlike that during heat exposure) and which one predominates depends upon such factors as environmental temperature, intensity of exercise, clothing insulation, and tissue insulation. In general, the oxygen cost of exercise in cold is commonly increased when compared with the cost of performing the same exercise intensity at normal environmental temperatures. From the data of Stromme, et.al. (20) where resting oxygen uptake is 50% higher in a 5°C (41°F) environment (Figure 1), one can see that at low exercise intensities oxygen uptake is higher than in a neutral environment; shivering and exercise have an additive effect on oxygen uptake. At higher exercise intensities (oxygen uptake of 1.2-1.5 L/min) there is no difference between the two environments. Thus, a critical level of heat production is required before the influence of cold-induced shivering is counteracted. Heart rate is also lower during light exercise in the cold when compared to a neutral environment due to the continued predominance of the cold stimulus over that of exercise (7). With increased exercise intensity, and thus decreased cold dominance, the heart rate comes under more normal cardiovascular control.

The competing stimuli of cold and exercise also effect the core and skin temperature responses. At low exercise intensities, the core temperature

Figure 1

cannot be maintained in the cold and will fall after about one hour of exercise (8). At higher intensities, rectal temperature begins to increase. This again leads to conflicting stimuli, which result in reduced shivering and sympathetic vasoconstrictor activity. The increased core temperature stimulates central thermoreceptors for heat loss. However, cold receptors in the skin are simultaneously signaling the thermoregulatory center to conserve heat. The result is that the skin temperature will decline or remain steady during exercise in the cold, but areas over active muscles will be at higher temperatures during exercise than at rest. This allows more heat to be lost thru convection and evaporation, although convection is the major avenue of heat loss during exercise in the cold.

#### MAXIMAL EXERCISE RESPONSES

Although little work has been done to determine the effects of cold on the capacity of the individual to perform maximal exercise, the available data show that maximal exercise responses (e.g. oxygen uptake, ventilation, heart rate, blood lactate) are unaltered during short term exposures (1-5 hr) to ambient temperatures as low as  $-20^{\circ}\text{C}$  ( $-4^{\circ}\text{F}$ ) (16). Thus, during maximal exercise, the exercise stimulus overrides that of cold such that the ability of the cardiovascular system to maximally transport oxygen to the exercising muscles remains intact.

However, a much different situation is seen if the core temperature is depressed. Bergh and Ekblom (4) induced different core and muscle temperatures in subjects by having them swim in cold water; they reported a decrease of 5-6% in maximal oxygen uptake and 8 beats per minute in heart rate per degree decrease in core temperature. They suggest that the primary effect of cold is a direct action on the heart, reducing the rate and thus the transport of oxygen to the muscle.

## ENDURANCE PERFORMANCE

The effects of acute cold exposure on the ability of the human to perform prolonged exercise have received little attention, and reports which have been published are largely anecdotal or subjective in nature. Over 40 years ago, Adolph and Molnar (1) reported that subjects became confused and exhausted while exercising on a cycle ergometer in an ambient temperature of  $0^{\circ}\text{C}$  ( $32^{\circ}\text{F}$ ) for one hour at an intensity they had easily maintained for four hours under warmer conditions. More recently, Faulkner, et.al. (6) reported a much poorer performance in all classes of skiers during the 1979 Canadian Ski marathon, where temperatures reached  $-28^{\circ}\text{C}$  ( $-18.4^{\circ}\text{F}$ ), compared to 1978 when conditions were considerably milder. This was largely attributed to the direct effects of cold, which appeared to induce an early onset of fatigue. Under more controlled conditions, Patton and Vogel (16) found a 40% decrease in submaximal endurance time to exhaustion using a cycle ergometer in subjects exposed to a chamber temperature of  $-20^{\circ}\text{C}$  ( $-4^{\circ}\text{F}$ ) compared to  $+20^{\circ}\text{C}$  ( $68^{\circ}\text{F}$ ).

Table 1

Factors which may explain the reported decrements in endurance performance in the cold are depicted in Table 1. As previously noted, a decrease in core temperature significantly reduces the transport of oxygen to exercising muscles. In addition, Bergh and Ekblom (4) also showed that the average endurance time during maximal intensity exercise is markedly reduced when core temperature is decreased.

A number of studies have demonstrated that a decrease in muscle temperature can drastically affect muscular contraction and thus exercise performance. In isometric contractions, force development is not significantly affected until muscle temperatures drop below  $27^{\circ}\text{C}$  ( $80.6^{\circ}\text{F}$ ). At

such temperatures, maximal tension development and endurance time are decreased (5). In contrast, dynamic muscular contractions are affected at much higher temperatures. Power output during maximal leg cycling declines approximately 4-6% per degree C from a muscle temperature of 38 to 30°C (100 to 86°F) as a result of a decrease in both the force and velocity of contraction (3).

There are several possible reasons why cooling may inhibit force production by the muscle. Vangaard (22) has shown that cooling of the motor fibers of the ulnar nerve decreases conduction velocity and thus the recruitment of muscle fibers close to the muscle surface. A lower muscle temperature would also presumably cause a decrease in the rate of chemical reactions in the muscle cell, decrease the rate of crossbridge formation, and increase the viscosity of the sarcoplasm, which would increase the resistance to crossbridge formation.

The energy expenditure of exercising in the cold is often greater than comparable activity in warm environments. Shivering, movement over snow and ice, as well as the weight and bulk of cold-weather clothing are the primary factors responsible for this added energy cost. With respect to the latter, it has been shown that as the bulk of the clothing worn is increased, there is an increased caloric expenditure which is greater than could be accounted for by the weight of the clothing alone. This extra caloric output has been attributed to a "hobbling effect", which is an interference of movement of the body's joints produced by the bulk of clothing. In addition, Teitlebaum and Goldman (21) demonstrated an increase in the metabolic cost of exercising with multilayered clothing over the corresponding cost of just carrying the weight and has attributed this to a "frictional drag" between layers as one layer of material slides over another during movement.



A decrease in the energy sources available for muscular contraction could also impact upon performance during cold exposure. Recently, Jacobs, et.al. (10) showed that glycogen utilization is increased 23% during light exercise at 9°C(48.2°F) compared to 21°C(69.8°F). This decrease in energy availability was attributed to the increased shivering thermogenesis of cold-exposure.

It is well known that dehydration has a marked affect on exercise performance in a warm environment. It is now recognized that the cold also provides an environment where severe dehydration can occur. In the cold there is an insidious loss of water as well as a decrease in the sensation of thirst. The loss of water is primarily from sweating in response to the increased energy demands of performing in the cold. Until recently, it had been thought that considerable water loss occurred from the respiratory tree as a result of humidifying the very dry air that is inhaled. However, recent data (14) suggest that only small amounts of water are lost even during the high ventilatory flows of exercise. An increase in urine production (diuresis) is known to occur during cold exposure primarily from the increased filling of the deep capacitance vessels which causes an indirect suppression of antidiuretic hormone. However, it is doubtful that this condition contributes significantly to the total water loss during prolonged physical activity in the cold.

#### Acclimatization to Cold

Considerable attention has been devoted to the question of how and to what extent man acclimatizes to cold. The published work in this area has been reviewed by Horvath (9) and by Haymes and Wells (7). Acclimatization refers to the physiological changes occurring within the lifetime of an

organism which reduce the strain caused by stressful changes in the natural climate. The human physiological adjustments to prolonged cold stress are less effective than those to heat. Much of the evidence for the existence of general acclimatization to cold is derived from the study of populations indigenous to cold climates. However, ethnic differences are more properly considered as adaptation and almost certainly involve the process of genetic selection. Information obtained from chronic exposure of individuals native to temperate regions is inconclusive and the question of whether humans can acclimatize to cold remains unresolved. However, some authors have reported a decrease in shivering after repeated cold exposures while others have reported an increased metabolic response. Such findings have led to the characterization of two patterns of general acclimatization - an insulative and metabolic type, respectively.

Interest has been expressed as to whether the state of an individual's physical fitness modifies the metabolic and circulatory responses to cold exposure. It has been suggested that improved physical fitness, brought about by strenuous muscular exercise, improves the tolerance to cold. Studies of the effect of physical conditioning on tolerance to cold have had, in general, a common pattern (9). Subjects are tested during a standard cold exposure before and after a period of exercise training lasting several weeks. In general, peripheral temperatures in the cold have been found to be slightly increased following training, but increased metabolic compensation for the higher peripheral temperatures has not been a consistent finding in every study. Indeed, data from the most recent study (12) showed decreases in metabolic rate and peripheral temperatures during acute cold exposure following 9 weeks of intense aerobic training. Thus the evidence is meager

that the physically fit individual is more tolerant of cold in a resting situation, and questions remain about the role that improved aerobic fitness has in modifying responses to a cold stress.

#### The Medical Threat of Cold

##### COLD AIR INHALATION

An interesting feature of exercise in the cold is the thermal protection of the upper airways during the performance of activities such as jogging or cross-country skiing. Although the physiological effects of cold air breathing are not fully known, studies on animals and humans have shown that the warming effects of upper respiratory passages preclude the possibility of cold injury to lung tissue. Upper airway freezing is relatively unknown, even under conditions of strenuous exercise in the cold. Recently, McFadden, et. al, (14) characterized the intrathoracic thermal events during cold air breathing ( $-18.6^{\circ}\text{C}$ ;  $-2.2^{\circ}\text{F}$ ) at multiple levels of ventilation by inserting a flexible probe containing thermistors into the tracheobronchial tree. At rest, temperatures ranged from  $29^{\circ}\text{C}$  ( $84.2^{\circ}\text{F}$ ) in the upper trachea to  $34^{\circ}\text{C}$  ( $93.2^{\circ}\text{F}$ ) in the subsegmental bronchi, and at ventilations in excess of 100 l/min, the temperatures in the proximal and distal airways were  $20.5^{\circ}\text{C}$  ( $68.9^{\circ}\text{F}$ ) and  $31.6^{\circ}\text{C}$  ( $88.9^{\circ}\text{F}$ ), respectively. They concluded that heat and water transfers were not confined to a single region of the tracheobronchial tree, but involved as much as was necessary to complete the task. The greater the ventilation and colder the inspired air, the lower the temperature of the gas at any point in the airways; thus air must travel further into the lung before it reaches body conditions of temperature and saturation.

McFadden, et. al.(14) further concluded that events transpiring during inspiration set the stage for thermal recovery during expiration. Heating and humidifying the air cools the mucosa, and as the air exits the alveoli, it begins to undergo a continuous loss of heat with a resultant drop in temperature and water vapor. On the average, the temperature of expired air tends to be 1-2°C greater than that during inspiration at any given location. As the temperature of gas decreases, so does the ability to hold moisture and the latter is conserved by condensation onto the airway surface. This information, therefore, does not support the notion that major degrees of airway drying take place when large thermal burdens are imposed on the airways since most of the water used to saturate the air upon inspiration would be recovered during the condensation that occurs during expiration.

Studies evaluating the effects of cold air breathing on airway resistance have found small but significant increases during inhalation (15). Such changes have been ascribed to the direct stimulation of tracheobronchial receptors which increase constriction since this response can be reversed by epinephrine (a bronchodilator). A greater concern, however, is the effect of cold-air inhalation during strenuous exercise. While no measurements of airway resistance have been made during exercise in the cold, a number of studies have shown that maximal ventilation is unaffected by cold-air breathing. Such data suggest that, in normal individuals, the stimulus of exercise and the associated increase in epinephrine secretion overcomes bronchoconstriction from cold air seen at rest. Thus, there is no reduction in the functional capacity of the respiratory system.

Individuals with certain medical conditions are at an increased risk of developing symptoms when exercising in a cold air environment. In the

asthmatic patient, the well documented phenomenon of exercise-induced bronchoconstriction is markedly enhanced when breathing cold air, while the effects of cold air at rest are very small (19). Thus, a positive interaction occurs between two common natural stimuli, in the induction of asthmatic attacks.

The symptoms of cardiac patients also can be exacerbated by the cold. Inhalation of, or exposure to, cold may precipitate angina pectoris (chest pain) at lower exercise intensities than would occur in a thermoneutral environment. The decreased tolerance is thought to result from an increase in the resistance to blood flow in response to the peripheral vasoconstriction which accompanies cold exposure. The consequent increase in blood pressure, by increasing the oxygen demands of the heart, provokes angina pectoris.

#### COLD INJURY

The principle medical problems which may occur from the exposure to a cold environment are frostbite and whole body hypothermia. The pathophysiology, recognition, and treatment of these conditions have recently been reviewed (2) and will be briefly outlined here.

Frostbite. This is the literal freezing of body tissue, typically in the extremities, which can lead to tissue loss if not detected and treated early. As ice crystals form in the extracellular spaces, water is drawn out of the cells, increasing the intracellular electrolyte concentration leading to the mechanical destruction of cells. Damage to blood vessels, particularly in endothelial cells, causes loss of vascular tubular integrity, resulting in tissue swelling and loss of distal nutritive blood flow. The severity of the injury depends on the length of time the tissue is frozen and the depth of

cooling. The longer the tissue remains frozen, the closer it gets to ambient temperature (assuming a significant below-zero ambience), and the more serious the injury will be.

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Table 2

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Frostbite can be divided into three stages, based upon the depth and thus the severity of the tissue freeze, as outlined in Table 2. Sometimes called frostnip, incipient frostbite usually only involves the tips of the ears, nose, toes, fingers, and the cheeks. The individual is usually unaware that frostnip has occurred until warned that the skin has become white or blanched. This condition develops slowly and is painless. Treatment is to rewarm the skin by applying firm pressure with a hand (no rubbing) or other warm body part, by blowing warm breath on the spot, or by submerging in warm water. The area will tingle slightly as it thaws.

Superficial frostbite involves the skin and the tissue just beneath the skin. While the skin itself is firm, white, and waxy in appearance, the tissue beneath it is usually soft. The skin should never be rubbed; as the area thaws, it will become purple or mottled blue and will tingle and burn after becoming initially numb. The area usually swells during thawing.

In deep frostbite, the tissue beneath the skin is solid to the touch; it may involve the entire hand or foot. This can result in permanent tissue loss if treatment is not immediately initiated. The treatment of choice is to rapidly rewarm the area by submerging in a 40°-44°C (104-110°F) water bath.

Frostbite is a preventable condition which occurs in anyone exposed to subfreezing temperatures without adequate thermal protection, or in those individuals whose sensorium is disturbed by alcohol or other drugs. Emergency procedures for frostbite are listed in Table 3. In general, frostbitten tissue should be kept frozen if there is any chance of

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Table 3

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refreezing. Tissue should be thawed rapidly because slow rewarming leads to greater tissue loss. However, care should be taken not to exceed a rewarming temperature of 44°C (110°F).

Hypothermia. This condition, defined as a core temperature of 35°C (95°F) or below, occurs in those who are unable to protect themselves from the cold or who do not recognize that they are losing heat rapidly. Although neonates, the elderly, and unconscious, immobile, or drugged persons are the usual victims of accidental hypothermia, the condition is now seen with increasing frequency in healthy young individuals who exhaust themselves during physical activity in a cold environment.

Table 4

The progressive clinical features of hypothermia, which are evident as body core temperature falls, are depicted in Table 4. Initial signs include fatigue, weakness, and slowing of gait. Uncontrolled, violent shivering is an important clue to an impending decrease in core temperature, but may not be detected during heavy exercise or when wearing protective clothing. As the core temperature declines, muscular coordination becomes affected, judgement is impaired and hallucinations may occur. At temperatures below 32°C (89.6°F), shivering will cease and further cooling will be rapid, with the loss of consciousness and marked effects on the cardiorespiratory system. The profoundly hypothermic patient is comatose and hyporeflexic. Death ensues as a result of ventricular fibrillation or cardiac standstill.

The prompt recognition of this life-threatening condition and the effective restoration of body heat are important prerequisites to a favorable outcome. Once an individual has been recognized as hypothermic, immediate steps should be taken to minimize further heat loss (remove wet clothing, keep dry, insulate, wrap in blankets, etc) and to add heat in whatever form

is available (give warm fluids, put in sleeping bag with warm rocks, heat packs, contact with another person, etc). If the hypothermic individual is unconscious, insulation and rapid transport to a medical facility are essential to a successful outcome. Rewarming procedures should not be attempted in the field situation since they are time-consuming and fraught with many medical problems which can not be addressed under such conditions.

The real key to effective management of the hypothermic person lies in prevention. Those who enjoy outdoor activities despite cold temperatures should be alerted to the risks of hypothermia, warned against the added hazards of wet conditions and wind chill, advised about clothing that provides maximal thermal protection, and be able to find shelter before the onset of exhaustion.

#### Prevention of Cold Injury

##### COLD INJURY AND EXERCISE

In contrast to the well publicized medical problems which arise from exercise performed in hot environmental conditions, relatively little attention has been paid to the potential for cold injury during prolonged exercise in a cold environment. However, there appears to be an increasing number of reports of hazards resulting from exhaustion due to physical activity in the cold. One of the best illustrations was depicted by Pugh (17) in a report on the 1964 Four Inns Walking competition, an event popular in the scouting movement in England, where three scouts lost their lives due to accidental hypothermia. While the race was well organized and all recognized safety precautions were taken, in retrospect, many conditions were present which are now known to contribute to fatal accidents during physical performance in the cold (e.g., wet-cold conditions, wind, inadequate clothing



worn by the hikers, fatigue and exhaustion). The inquest summary and interpretation by Pugh should be required reading for all individuals engaged in exercise in cold environments.

More recently, Jones et al (11) reported that the most common medical diagnosis, following a cool weather marathon ( $7.9-10.8^{\circ}\text{C}$ ;  $46.2-51.4^{\circ}\text{F}$ ) was hypothermia. This was based upon symptoms of uncontrolled shivering and complaints of cold. Maughan, et. al. (13) further reported that a decrease in core temperature is not uncommon following a marathon run in cool conditions, particularly in inexperienced runners who frequently run the second half more slowly than the first half. Such runners may be able to maintain core temperature initially, but with the slow pace of the second half, especially on cool, wet and windy days, hypothermia can develop. Race organizers and medical teams who deal with such events, as well as individuals who participate in any outdoor physical activity, should be aware of the risks of hypothermia and be prepared to deal with them.

#### RISK FACTORS FOR COLD INJURY

The maintenance of homeothermy and prevention of peripheral cold injury depend upon a balance between climatic factors, on the one hand, and protective clothing and the individual's ability to generate body heat, on the other. There are a number of factors which place an individual at an increased risk for the development of cold injury. These are shown in Table 5.

The presence of moisture in clothing or on the skin markedly increases the heat lost by the body, and increases one's susceptibility to cold injury. Clothing insulation can be reduced up to 30% as the water content increases either from internal sweat production or from external sources such as rain

and snow. Sweating is a problem for many athletes who exercise in the cold, particularly during periods of low activity or rest when heat is lost rapidly from the body when clothing is wet.

Wind is another condition which can be devastating to the maintenance of a normal body temperature. As the velocity of air movement increases, the convective heat loss increases, reducing the skin temperature and increasing the risk of frostbite. Heat loss is particularly increased if wind is allowed to penetrate the outer garments, thereby reducing their insulation. The windchill index is a very valuable instrument, therefore, in evaluating the combined effects of air velocity and temperature on subjective comfort and the danger of freezing injury (Figure 2).

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Figure 2

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Clothing is obviously a crucial factor in combating the effects of temperature, moisture, and wind; clothing should vary based upon the severity of these conditions. The effective insulation provided by clothing is a function of the air layer next to the skin, the thickness of the clothing and the amount of air trapped in the layers. The two basic principles in the proper use of clothing are that it be multiple layered and that it allow for adequate ventilation.

Multilayered clothing systems are essential during exercise in the cold because layers can be removed to balance the amount of insulation to the level of energy expenditure. The outer layer should be both water repellent and wind resistant, with the inner layers providing the insulation. Wool, goose down, and synthetic fibers all have good insulative qualities by effectively trapping air within the garment. The innermost layer should not only provide insulation but also remove (wick) moisture away from the skin to reduce evaporative heat loss. To provide maximum protection, clothing must also be kept clean and dry.

The use of any foreign substance which promotes either heat loss or interferes with central thermoregulation obviously enhances the risk of developing cold injury. Alcohol ingestion is a particular problem, in that it not only promotes peripheral vasodilatation, thus increasing heat loss, but also lowers blood glucose levels. This, in turn, inhibits shivering and increases the susceptibility to hypothermia. Skiers and other outdoor enthusiasts should be aware of these effects and the increased risks when alcohol is consumed.

#### Summary

Humans respond to the effects of a cold environment by increased tissue insulation (peripheral vasoconstriction) and increased heat production (shivering thermogenesis). The stimulus of exercise, however, results in opposite, conflicting physiological responses. Whether the physiological effects of cold or exercise predominate depends upon the ambient temperature, intensity of exercise, and the amount of clothing insulation.

Performance in endurance activities (cross-country skiing, running) is impaired if conditions such as a decrease in core or muscular temperature, shivering, or dehydration occur. From a tactical standpoint, an athlete should avoid both shivering and sweating. Optimally, plenty of clothes should be worn that can be discarded immediately before competition.

Performance in events that require dynamic muscle strength and power (e.g. football) will be markedly affected by the peripheral cooling of muscles. Such sports involve intermittent activity and are more likely to be affected by cold than sports of continuous activity. Adequate clothing must be provided on the sidelines, to keep the body warm before and during such activities, and thereby prevent muscles from cooling.

There is not a specific air temperature which is too cold for exercise. Breathing cold air will not injure the lungs, but the dryness may cause some irritation and discomfort to the nasopharynx. The decision to exercise in the cold should be based upon the potential danger of developing cold injury. The judicious use of the windchill index (Figure 2) will greatly reduce the possibility of cold injury. Temperatures in the "increasing danger" area may make it prudent to cancel or shorten outdoor training. Wind, rain, or snow are the more important variables influencing an athlete's decision to train.

The major cold injuries which can occur from exercise in the cold are frostbite and hypothermia. Factors which increase the risk for the development of these conditions are: low ambient temperature, moisture, wind, inadequate clothing, fatigue, dehydration, and alcohol or drug use.

The level of individual activity is an important determinant of the amount of clothing required for safety and comfort. The layering principle should be applied when selecting clothing for cold weather exercise. To protect against the wind and moisture, the outer layer should be wind and water resistant. The inner layers should provide adequate insulation, with the innermost layer acting to wick water from the skin surface.

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Table 1. Factors responsible for reduced endurance performance during cold exposure

1. Decrease in core temperature
2. Decrease in muscle temperature
3. Increase in energy expenditure
  - Shivering
  - Added cost of moving over snow/ice
  - Mass and hobbling effect of clothing
4. Increased energy substrate utilization
5. Dehydration



Table 2. Stages of frostbite.

1. Incipient (Frostnip)  
Affects tips of ears, nose, cheeks, fingers, toes  
Person unaware, skin blanched, painless  
Warm with body parts, blowing warm air, warm water
2. Superficial  
Affects skin and tissue just beneath skin  
Skin is firm and waxy, tissue beneath is soft,  
numb, then turns purple during thawing  
Place in warm water, provide steady warmth
3. Deep  
Affects entire tissue depth  
Tissue beneath skin is solid, waxy white with  
purplish tinge  
Rewarm rapidly in 40-44°C (104-110°F) water bath

**Table 3. Emergency procedures for treatment of frostbite.**

1. Keep tissue frozen until treatment can be initiated  
Do not allow refreezing
2. Do not delay transport for rewarming
3. Rewarm tissue rapidly, not gradually
4. Do not use excessive heat to thaw the tissue
5. Bandage with loose, sterile dressings
6. Do not rupture blisters
7. Do not massage, rub snow or ointments on tissue

Table 4. Clinical features of hypothermia.

<u>Core Temperature</u>		<u>Signs/Symptoms</u>
<u>°C</u>	<u>°F</u>	
35.0	95.0	Violent shivering, fatigue, feeling of extreme cold
34.0	93.2	Loss of coordination, slurred speech, poor judgement, memory lapses
32.0	89.6	Consciousness clouded, disorientation, dizziness, shivering ceases
30.0	86.0	Slow pulse and respiration, blood pressure difficult to obtain, progressive loss of consciousness
28.0	82.4	Ventricular fibrillation may develop if heart irritated, voluntary motion and reflexes lost
26.0	78.8	Spontaneous ventricular fibrillation, cardiovascular death
15.0	59.0	Lowest temperature from which recovery was achieved

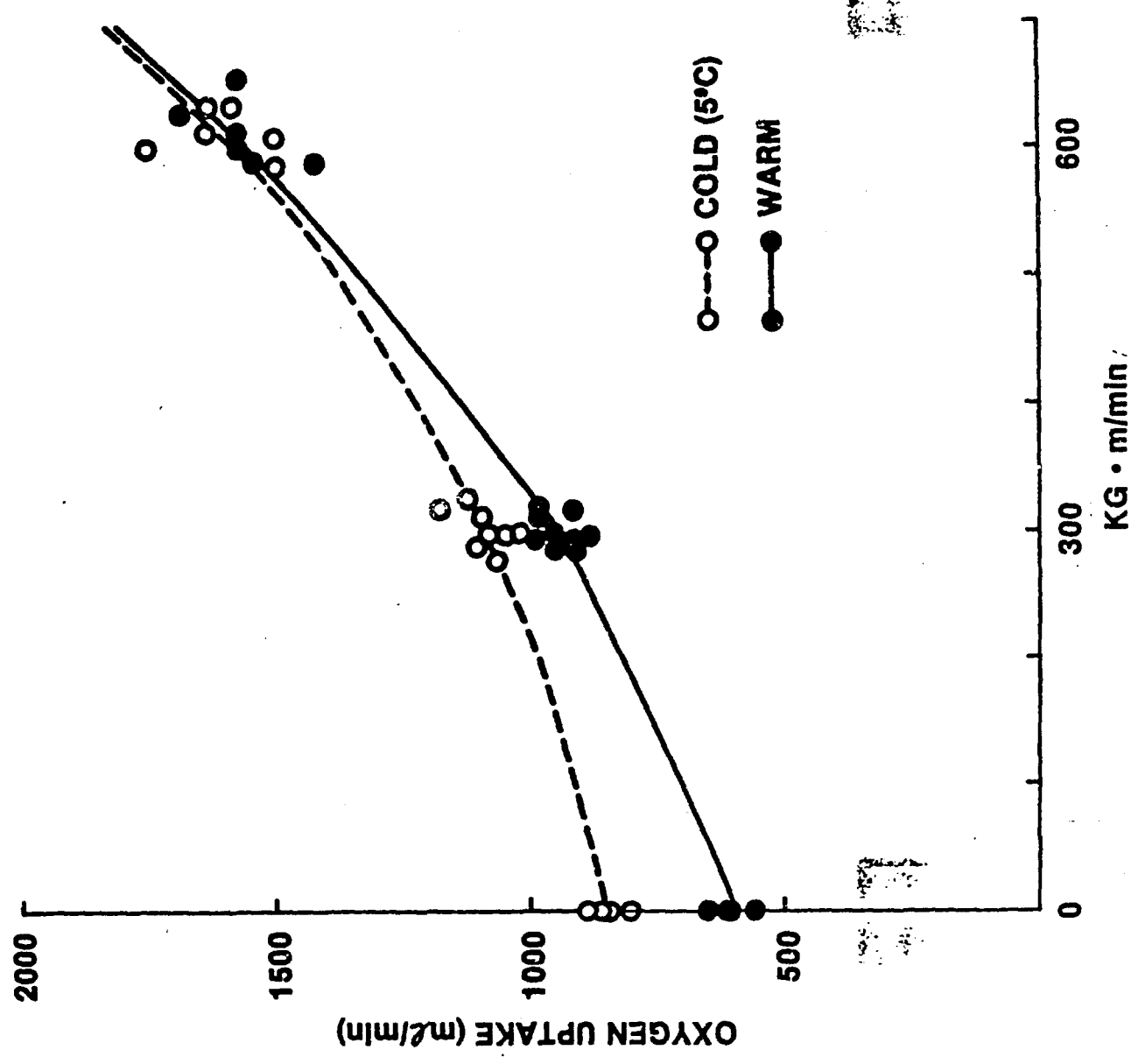
Table 5. Risk factors for cold injury.

1. Ambient temperature
2. Moisture
  - Reduces clothing insulation
  - Increases heat loss
3. Wind
  - Increases convective heat loss
  - Decreases clothing insulation
  - Windchill index
4. Clothing
  - Multilayer
    - Outer - water repellent
    - wind resistant
  - Inner - insulation
  - Innermost - wick
  - Clean, dry, lightweight
  - Ventilation
5. Other
  - Poor nutrition
  - Fatigue/exhaustion
  - Alcohol, tobacco, drugs
  - Dehydration

### Figures

1. Oxygen uptake during cycle ergometer exercise in a warm ( $26^{\circ}\text{C}$ ) and cold ( $5^{\circ}\text{C}$ ) environment. Redrawn from figure originally published by Stromme, et.al.(20).
2. Windchill factor chart - the cooling power of wind on exposed flesh expressed as an equivalent temperature.

Figure 1.



Windchill factor chart										
Actual thermometer reading	Estimated wind speed in mph (and kph)									(Wind speeds greater than 40 mph have little additional effect.)
	calm	5 (8)	10 (16)	15 (24)	20 (32)	25 (40)	30 (48)	35 (56)	40 (64)	
	EQUIVALENT TEMPERATURE IN °F (AND °C)									
80°F (10°C)	50 (10)	48 (8.9)	40 (4.4)	36 (2.2)	32 (0)	30 (-1.1)	28 (-2.2)	27 (-2.8)	26 (-3.3)	LITTLE DANGER (for properly clothed person Maximum danger from false sense of security
40°F (4.4°C)	40 (4.4)	37 (2.8)	28 (-2.2)	22 (-5.6)	18 (-7.8)	16 (-8.9)	13 (-10.6)	11 (-11.7)	10 (-12.2)	
30°F (-1.1°C)	30 (-1.1)	27 (-2.8)	16 (-8.9)	9 (-12.8)	4 (-15.6)	0 (-17.8)	-2 (-18.9)	-4 (-20)	-6 (-21.1)	
20°F (-8.7°C)	20 (-6.7)	16 (-8.9)	4 (-15.6)	-5 (-20.6)	-10 (-23.3)	-15 (-26.1)	-18 (-27.8)	-20 (-28.9)	-21 (-29.4)	
10°F (-12.2°C)	10 (-12.2)	6 (-14.4)	-9 (-22.8)	-18 (-27.8)	-25 (-31.7)	-29 (-33.9)	-33 (-36.1)	-35 (-37.2)	-37 (-38.3)	INCREASING DANGER Danger from freezing of exposed flesh
0°F (-17.8°C)	0 (-17.8)	-5 (-20.6)	-24 (-31.1)	-32 (-35.6)	-39 (-39.4)	-44 (-42.2)	-48 (-44.4)	-51 (-46.1)	-53 (-47.2)	
-10°F (-23.3°C)	-10 (-23.3)	-15 (-26.1)	-33 (-36.1)	-45 (-42.8)	-53 (-47.2)	-59 (-50.6)	-63 (-52.8)	-67 (-55)	-69 (-56.1)	
-20°F (-28.9°C)	-20 (-28.9)	-26 (-32.2)	-46 (-43.3)	-58 (-50)	-67 (-55)	-74 (-58.9)	-79 (-61.7)	-82 (-63.3)	-85 (-65)	GREAT DANGER
-30°F (-34.4°C)	-30 (-34.4)	-36 (-37.8)	-58 (-50)	-72 (-57.8)	-82 (-63.3)	-88 (-66.7)	-94 (-70)	-98 (-72.2)	-100 (-73.3)	
-40°F (-40°C)	-40 (-40)	-47 (-43.9)	-70 (-56.7)	-85 (-65)	-96 (-71.1)	-104 (-75.6)	-109 (-78.3)	-113 (-80.6)	-116 (-82.2)	
-50°F (-45.6°C)	-50 (-45.6)	-57 (-49.4)	-83 (-63.9)	-99 (-72.8)	-110 (-78.9)	-119 (-83.3)	-125 (-87.2)	-129 (-89.4)	-132 (-91.1)	
-60°F (-51.1°C)	-60 (-51.1)	-68 (-55.6)	-95 (-70.6)	-112 (-80)	-124 (-86.7)	-133 (-91.7)	-140 (-95.6)	-145 (-98.3)	-148 (-100)	

Figure 2